Water Quality as a Contemporary Limiting Factor to Olympia Oyster (*Ostreloa conchaphila)* Restoration in Washington State

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Abstract
The purpose of this study was to define the response of Olympia oyster to the contemporary water quality environment of Puget Sound. Through a one-year field experiment, Olympia oyster growth, mortality, and tissue loading of metal and organic pollutants was assessed to define the role water quality may play in restoration of Olympia oyster to Washington waters. Results indicate that nonpoint source pollution of non-metropolitan areas, a significant contemporary water quality feature for inland marine waters of Washington, does not appear prohibitive to Olympia oyster restoration. While keen assessment of potential sites is a critical component to oyster restoration, water quality may be less of a factor than other limiting factors, such as predators, for initial site selection. Within the range of this study, high levels of fecal coliform levels, turbidity, or organic pollutants do not appear to be indicators of poor Olympia oyster habitat. High cadmium levels may impact Olympia oyster growth and mortality and so may be a concern for restoration success. Sites with elevated cadmium and zinc should therefore be given extra consideration and possibly lower priority. The Olympia oyster's tolerance for contemporary water quality is an encouraging factor when considering Olympia oyster restoration options.

Introduction
The Olympia oyster (*Ostreloa conchaphila)* occurs in marine waters from Bahia de San Quentin, Baja California, to Sitka, Alaska (Ricketts and Calvin 1968). It primarily inhabits sheltered waters or estuaries, often near creek mouths (Baker 1995). Once common in Washington state, the Olympia oyster now has a restricted and very patchy distribution in Willapa Bay, Grays Harbor, Hood Canal, and southern Puget Sound.

The Olympia oyster has been the focus of human harvest for several thousand years. The oyster has an important identity for the Washington tribes who used the oyster, named Tusa'yad by the Skokomish Tribe, extensively, and often based settlement locations on its harvest (Washington Secretary of State 1935; Elmendorf and Kroeber 1992; Steele 1957). With European colonization, the Olympia oyster supported a large commercial industry. Olympia oyster beds from Puget Sound, Hood Canal, and Willapa were harvested extensively, and later cultivated with an elaborate system of dikes (Steele, 1957; Westley 1971; Brown 1976). Over harvesting in the late 1800s and water quality problems in the 1930s to 1950s caused Olympia oyster stocks to crash, and the industry to terminate (Baker 1995; Lindsay and Simons 1997).

Pollution has been shown to be the number one factor in the demise of the Olympia oyster throughout lower Puget Sound and Hood Canal. Sulfite waste liquor (SWL) from the Rayonier pulp mill was released into Oakland Bay from 1927 to the 1950s. Tidal currents carried effluent to Oakland Bay beds within a tidal cycle, and throughout lower Puget Sound within a matter of days (McNennan *et al.* 1949). Crashes were witnessed throughout the Olympia oyster beds, and the industry ended by the mid 1940s (Lindsay and Simons 1997; D.McMillin pers comm.). The Rayonier mill was closed in 1957. Unfortunately, the Olympia oyster industry had largely terminated by that time, so monitoring of the populations of Puget Sound and southern Hood Canal had ceased (Steele 1957; Gunter and McKee 1960).

Water quality impacts in Washington's waters has shifted over the last 40 years from industrial effluent to now include significant nonpoint source pollution, including stormwater run off from roads, cities, and agricultural areas (Department of Ecology 1998). Impacts of contemporary water quality degradation to remaining Olympia oyster stocks are not known. Contemporary water quality impacts to Olympia oysters of the coast and inland waters include low dissolved oxygen (DO), chlorine from sewage outfalls, non-point pollution and associated eutrophication, sedimentation and siltation, and herbicides (Couch and Hassler 1989; Cook *et al.* 2000; McMille, 1978).

Efforts to restore Olympia oysters within Washington waters are now underway. The Washington State Department of Fish and Wildlife (WDFW) recently developed a stock rebuilding strategy (Cook *et al.* 2000). The Puget Sound Restoration Fund, a consortium of Puget Sound businesses, is working with Tribes and local citizens groups to restore Olympia oyster in each county within Puget Sound, Hood Canal, and the Strait of Juan de Fuca. Limiting factors for restoration, including the role of contemporary water quality of these waters, have not been analyzed in the field. Given the important role of water quality to the history of Olympia oyster, it is a historic limiting factor of high contemporary interest.

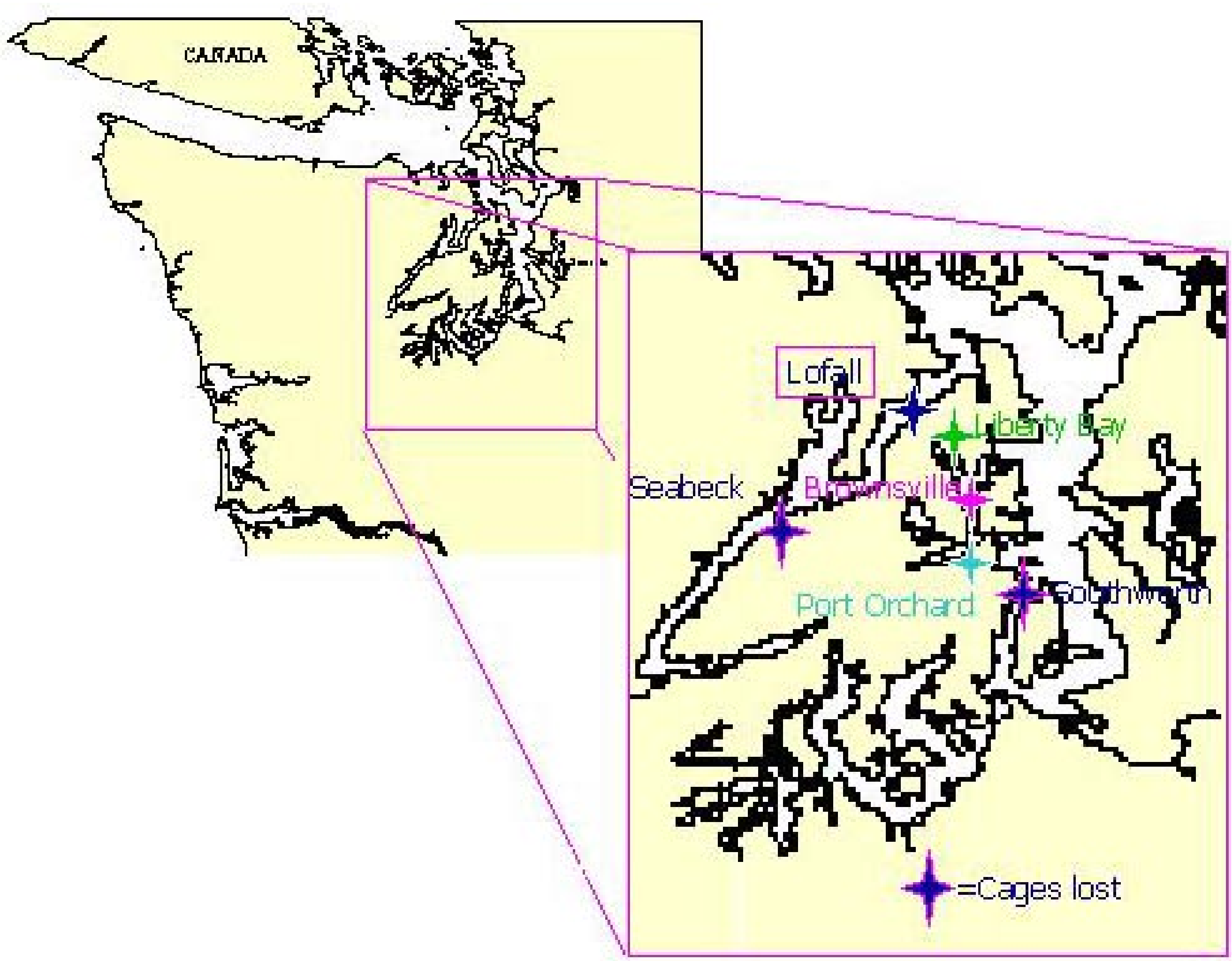

Figure 1. Olympia oyster study sites.

The purpose of this study is to therefore define the response of Olympia oyster to the contemporary water quality environment of Puget Sound. Through a one-year field experiment, Olympia oyster growth, mortality, and tissue loading of metal and organic pollutants was assessed to define the role water quality may play in restoration of Olympia oyster to Washington waters.

Methods and Materials

Six sites in non-metropolitan but populated areas of Puget Sound and Hood Canal, were chosen for this study (Figure 1). These sites represented three each of good and degraded water quality. Degraded water quality sites exceeded state and county water quality standards for fecal coliform counts or levels of toxic metals and pesticides, while good water quality sites were within state and federal standards.(Kitsap Co. unpublished data.). Mature Olympia oysters were collected from Case Inlet (Southern Puget Sound) in 1997. These oysters were spawned at the WDFW shellfish hatchery at Brinnon, and post settlement larvae grown for 12 months. One hundred twenty five one-year-old oysters were placed in .130 m^2 plastic trays. To determine growth, a sub-sample of 25 from each tray was measured at the beginning and end of the field work. Four trays were bundled into one rack which was then set at each site in May 1998, and retrieved in April 1999. All oysters were counted and 25 oysters from each tray measured. Dead oysters were also counted. Growth and number survived were calculated for each site. These data were found to be non-normal and so were log transformed. One-way ANOVA with replication was conducted to determine significant differences in growth and survival between sites.

At the beginning and end of the study analysis for metals and organics was conducted on tissue pooled from five oysters from each tray. Tissue samples from the beginning of the study were designated ‘baseline’. Results of tissue analysis were compared to detection levels by site. Tissue loading that exceeded detection levels for metals and PCBs was noted by site. Olympia oyster tissue levels were compared to Littleneck clam (*Prototheca* sp), and Pacific oyster (*Crassostrea gigas*) tissue collected from same sites over a two-three year period.

Each site was monitored for water quality and sampled monthly for fecal coliform counts, temperature, turbidity, salinity, pH, and percent dissolved oxygen. Regressions were conducted between Olympia oyster mortality, growth, and tissue levels of organics and metals and basic water quality parameters. Results were summarized and compared by site.

Results

Trays from two of the good water quality sites were lost due to vandalism. Analysis of samples from the three substandard water quality sites, called Brownsville, Port Orchard, and Liberty Bay, and remaining one control site, Lofall, follow. Mortality and growth of remaining oyster were significantly and positively related ($t=19.66$; $p=0.0025$).

Mortality: Average number of Olympia oyster mortality by site ranged from 2-19%, with the highest mortality occurring at the clean water (Lofall) site. Port Orchard, Brownsville, and Poulsbo had 2, 7, and 11 percent loss respectively.

Growth: Olympia oysters at Lofall, the remaining good water quality site, had significantly lower growth than any of the other sites, with an average change of 13.51 mm. Brownsville and Port Orchard had the highest change in size, and grew 20.07mm and 20.58 mm respectively. Growth at these two sites was not significantly different from each other. Oysters from all other sites had significantly different growth rates (Table 1).

Table 1. Size change of Olympia oyster at five sites of Puget Sound 1998-1999.

Tukey test	Size change, mm	Site comparison	q	$P_{.05, 9, 25}$
		Port Orchard - Lofall	23.15162	<.001
Port Orchard	21	Port Orchard - Poulsbo	15.65019	<.001
Brownsville	20	Port Orchard - Brownsville	1.385879	NS
Poulsbo	15	Brownsville - Poulsbo	14.26432	<.001
Lofall	13	Poulsbo - Lofall	7.501429	.001<.005

Tissue analysis: Olympia oyster tissue analysis results, as expressed as amount over detection level, are summarized in Figure 2.

Metals: Oysters from all sites had low cadmium and mercury levels. Copper and zinc were in highest concentrations. Oysters from Lofall, Poulsbo, and Port Orchard had the highest levels of cadmium and zinc, while Poulsbo and Port Orchard had the highest levels of copper. Brownsville had the lowest levels of cadmium, copper, and zinc.

Comparing levels of metals in bivalve tissues sampled from the four sites over two years show that Olympia oysters had higher tissue concentrations of arsenic, copper, zinc, and lead and than either *Crassostrea gigas* (Lofall site), or littleneck (*Prototheca/Venerupis* spp) (Figure 3). Olympias had consistently lower levels of mercury. Levels of cadmium in Olympia oyster tissue relative to other bivalves varied by site.

Few trends between oyster mortality and metals were evident. Regression analysis revealed a significant positive relationship between cadmium and oyster mortality ($t=3.942$; $p=0.05$) and a significant negative relationship between oyster growth and cadmium levels ($t=22.59$; $p=0.001$). While not a significant relationship, it is of note that zinc appeared to have low positive regression, and that high zinc levels at Lofall and Poulsbo correspond with lowest growth and highest mortality of the four sites. Conversely, highest growth and lowest Olympia oyster mortality were observed at Brownsville, the site with lowest cadmium and zinc levels.

Organics: Lofall had the lowest levels of organics for all sites. Port Orchard and Poulsbo had elevated levels of AR 1260 and AR 1254S. PP DDE was found to exceed detection levels at all three substandard sites. Of these, Poulsbo and Port Orchard had the highest levels. Only ppddds showed a significant (positive) relationship with growth (($t=19.77$; $p=0.0025$). Levels of organics in tissue of other bivalves sampled did not exceed detection values, and so could not be compared to Olympia oyster.

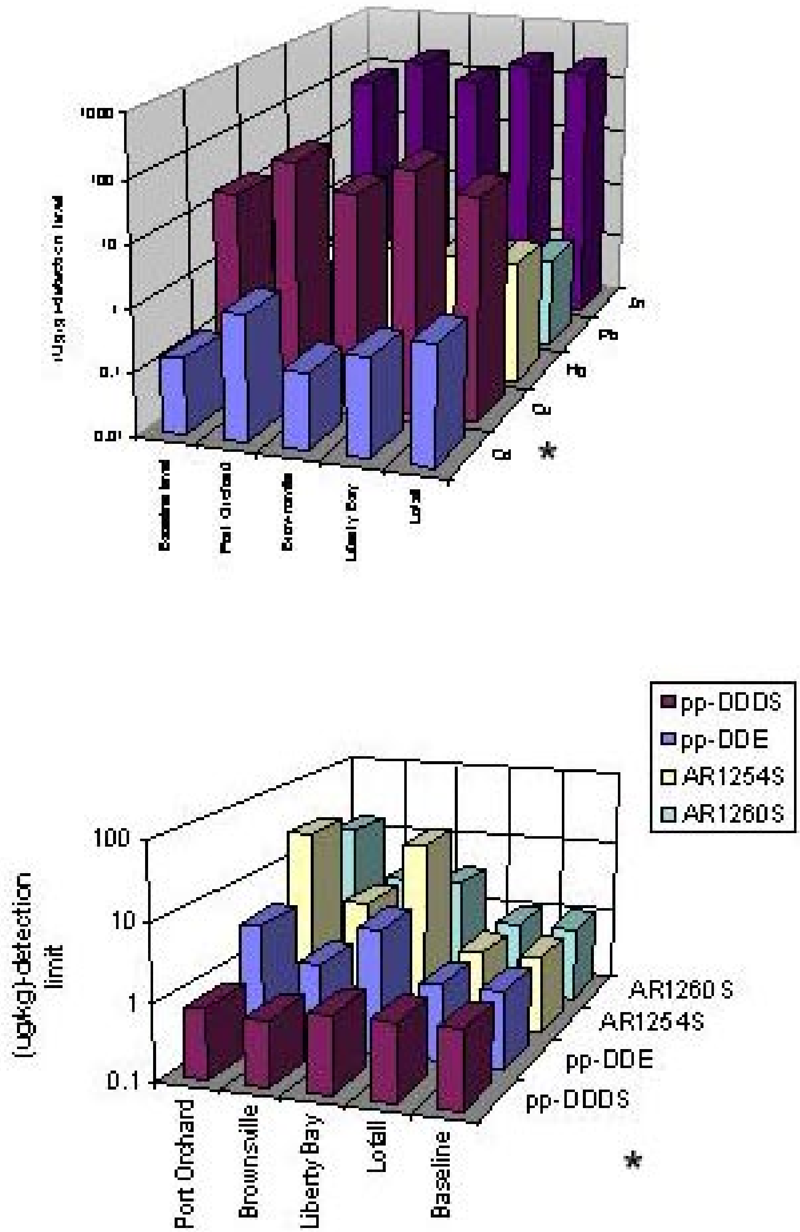

Figure 2. Olympia oyster tissue analysis, metals and organics (*=growth correlation significant =p<.05).

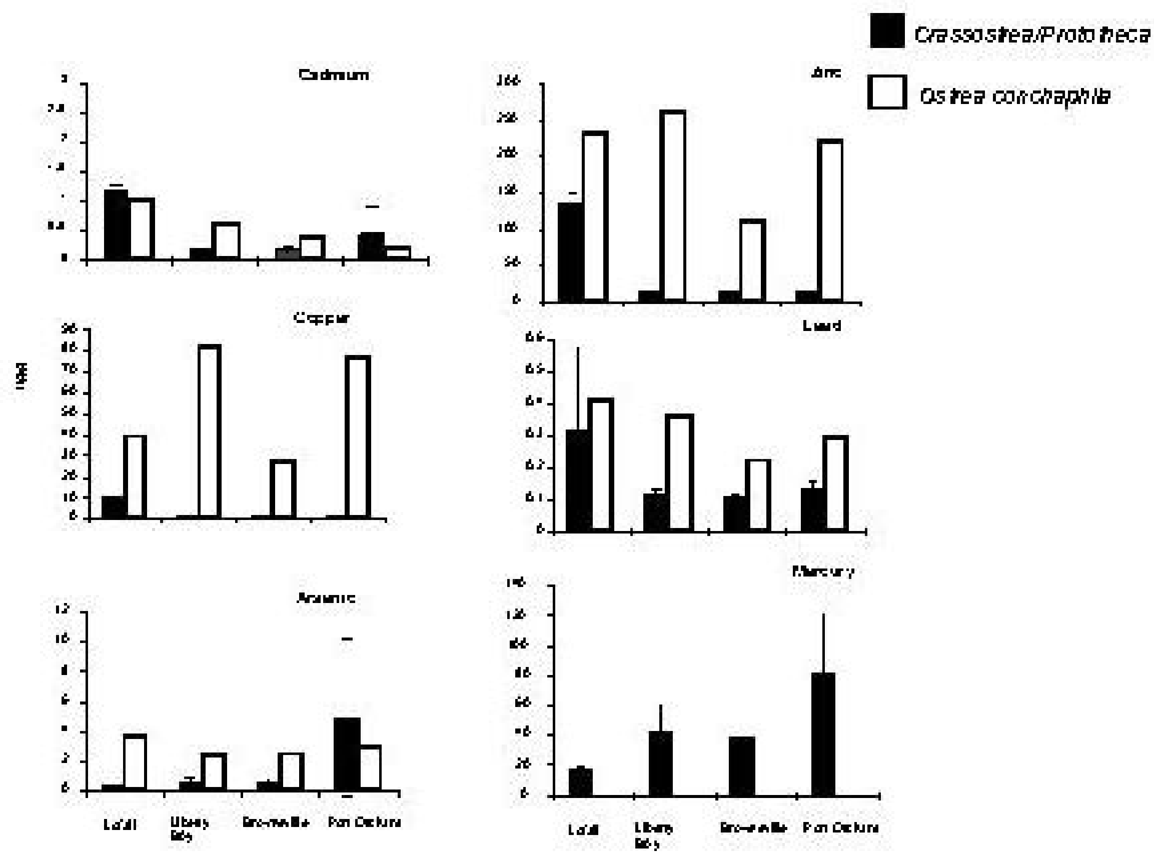

Figure 3. Comparison of metals in bivalve tissue for Puget Sound sites (Olympia oyster sampled in 1999; all other species averaged data with standard error from 1996-1998, Kitsap County, unpublished data).

Water quality: Summaries of water quality for the four remaining sites at the conclusion of the study are given in Figure 4. Lofall was the only site to pass County and state standards for Class A waters (Kitsap Co. unpublished data). Brownsville, Port Orchard, and Liberty Bay (Poulsbo) exceeded standards for DO, fecal coliform, and temperature. When averaged over thirteen months, all sites had high percent oxygen saturation. Brownsville had the highest turbidity and fecal coliform levels of all sites. Lowfall had the lowest turbidity and fecal coliform.

Regression analysis revealed positive, significant trends between number of oyster lost and growth of remaining oyster ($t=19.66$; $p=0.0026$), and significant relationship between growth of oyster and fecal coliform concentrations ($t=6.757$; $p=0.02$) and turbidity ($t=5.708$;$p=0.029$). Growth was not significantly related to temperature ($t=0.944$; $p=0.445$), and mortality was not significantly related to any other water quality parameter.

Discussion

Olympia oyster fared well in substandard water bodies of this study. The 18% mortality observed coincides with mortalities observed in control sets of Olympia oyster in sulfur waste liquor (SWL) studies (Woelke and Anderson 1966). Of interest is the fact that in this study the site with the best overall water quality had the lowest growth and highest mortality of Olympia oyster. Low mortality and high growth of Olympia oyster in areas with high fecal coliform levels illustrate an adaptation to seasonally warm, turbid, nutrient rich water that occur in Puget Sound embayments. This site also had the lowest cadmium and zinc levels of the four sites sampled, which may indicate a negative relationship between cadmium, zinc, and Olympia oyster growth and survival. Tissue levels of cadmium observed in this study are low compared to those threshold levels reported for growth and mortality of other species of bivalve (Poulsen *et al.* 1982; Rule and Alden 1996). The relationship between cadmium, and oyster growth and mortality observed in this study may signal a higher sensitivity by Olympia oyster to cadmium. More detailed work is needed to confirm and clarify this relationship.

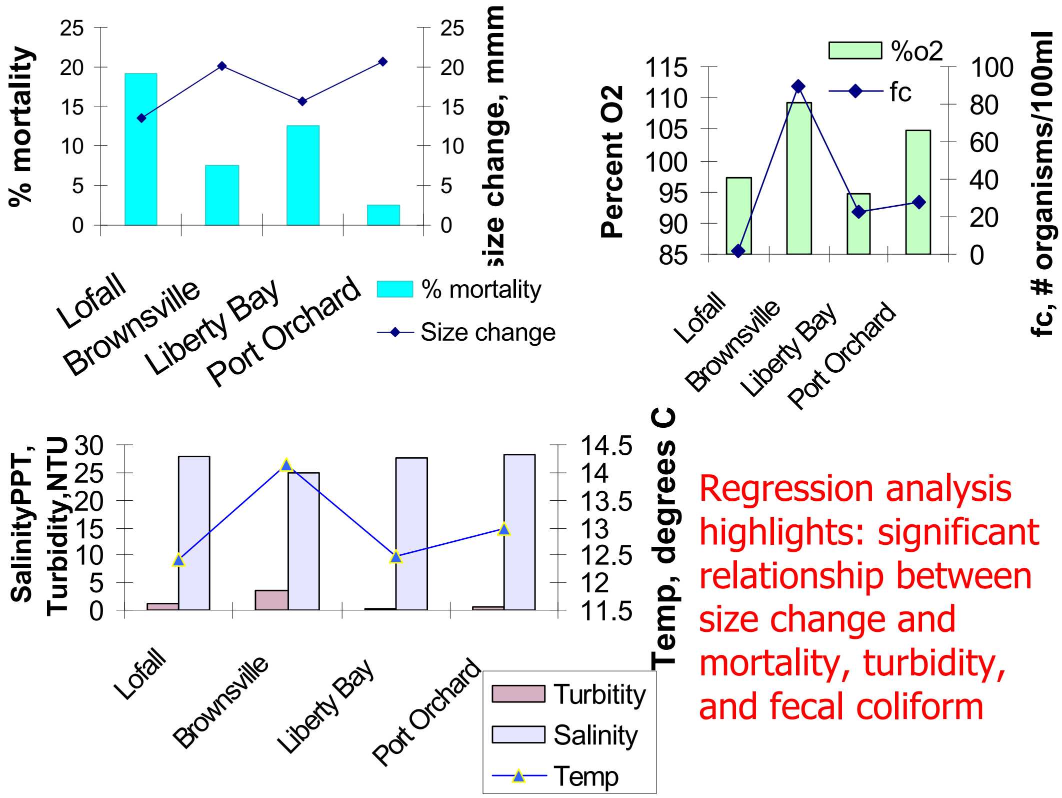

Figure 4. Olympia oyster percent mortality, growth, and basic water quality parameters at four sampling sites (water quality data averaged over 13 months).

It is also important to note that seed used in this study was 1-year old and so may not have been as sensitive to water quality. This should be kept in mind when comparing these results to earlier work. Olympia oysters are documented to be very sensitive to some pollutants. Woelke and Anderson 1966 report 34% mortality of adult oyster at 100ppm of 10% solid sulfite waste liquor (SWL). McKeran *et al.*1949 observed harmful effects at 64ppm SWL. In the lab Woelke 1956 and Woelke and Anderson 1966 reported SWL as deleterious to Olympia oyster larvae and adults at 8ppm.

Relative to sulfite waste liquor pollution, the degraded water quality environment of this study does not appear to significantly impact Olympia oyster growth and survival. While sites selected in this study are representative of the majority of Puget Sound and Hood Canal, these results cannot be extrapolated to heavily polluted water bodies of Puget Sound, which include superfund sites and large urban/metropolitan areas. More work is needed to define success of Olympia oyster in these areas.

Higher levels of both metals and organics (with the sharp exception to mercury) in Olympia oyster tissue relative to other bivalve tissue may reflect higher filter feeding efficiency than other clam and oyster species used for water quality monitoring studies. The reason for consistently lower values of mercury in Olympia oyster tissue is not clear. Barring this metal, the results indicate that Olympia oyster may be another good candidate species for water quality monitoring.

In summary, nonpoint source pollution of non-metropolitan areas, a significant contemporary water quality feature for inland marine waters of Washington, does not appear prohibitive to Olympia oyster restoration. While keen assessment of potential sites is a critical component to oyster restoration, water quality may be less of a factor than other limiting factors, such as predators, for initial site selection. Within the range of this study, high levels of fecal coliform levels, turbidity, or organic pollutants do not appear to be indicators of poor Olympia oyster habitat. High cadmium and zinc levels may be a concern for restoration success, and sites with elevated cadmium and zinc should be given extra consideration and possibly lower priority. The Olympia oyster's tolerance for contemporary water quality is an encouraging factor when considering Olympia oyster restoration options.

Results of this study also indicate that Olympia oyster is effective at bioaccumulating metals and organics. This species might therefore be a good candidate species for water quality monitoring studies, particularly if mercury detection questions can be answered. Olympia oysters are particularly attractive for water quality monitoring given the priority for restoration and cultural importance of the species for Washington.

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